

ELECTRON CLOUD AND PRESSURE RISE SIMULATIONS FOR RHIC*

U. Iriso-Ariz†, M. Blaskiewicz, A. Drees, W. Fischer, S. Peggs, D. Trbojevic.
BNL, Upton, NY 11973, USA

Abstract

Beam induced electron multipacting may be among the main reasons for the vacuum pressure rise when circulating high intensity ion and proton beams in RHIC. Latest simulation results are benchmarked with recent experimental observations for RHIC, and compared to other general computer codes. The influence of the electron multipacting to the vacuum properties is also discussed.

1. INTRODUCTION

Pressure (P) rises were observed as bunch currents were increased during both gold (Au) and proton (p) operations at the Relativistic Heavy Ion Collider (RHIC). Preliminary indications from the RHIC 2001 run [1] suggest that an electron cloud (EC) may be the main cause of P rises that limit the beam intensity at RHIC. Ion desorption and beam loss may also be partially responsible. In the following, we benchmark the latest experimental observations with one of the existing computing codes, *CSEC* [2]). Preliminary results obtained from *ECLOUD* [3] are also discussed. Following the results obtained by *CSEC* and the experimental data, we give a reliable ranges for the main wall surface parameters contributing to the effect, which are necessary to determine the behaviour of the secondary electron emission, δ (Sec. 2). Observations have been made with the same fill pattern (106ns bunch spacing) and during the same process (injection, where bunches are typically 15ns head-to-tail long) as in the 2001 run. Due to the bake out carried out during the RHIC shutdown in 2002, the 55 bunch fills (with 216ns bunch spacing) did not show EC effects. Due to the high P rise observed in some cases, the number of injected bunches injected did not reach the target of 110. We also compare the simulation results with data when a solenoidal field is applied to suppress the effect. The experimental results are based on the electron detector in [4]. The direct output provided by this detector is a voltage, which can be converted to a current into the wall (I_{wall}) with a large uncertainty (factors ≈ 3 are possible [4]). Despite this large error, it has been decided to show the experimental observations in terms of I_{wall} , expressed in ($\frac{\mu A}{cm^2}$). Finally, and based in the experimental data, we discuss the influence of I_{wall} to the P for when the latter reaches a final steady state.

2. PARAMETRIZATION OF THE SECONDARY EMISSION YIELD

Following the notation in [5], for a normally incident electron with kinetic energy E , $\delta(E)$ is the total number of electrons leaving the surface due to all processes. The parametrization of $\delta(E)$ is one of the main concerns while simulating the EC effect, and there are still a lot of investigations currently being carried out [7]. *CSEC* uses the following [2]:

$$\delta(E) = (R - R_{inf}) \exp^{-E/E_r} + R_{inf} + SEY_{max} \frac{s(E/E_{max})}{s - 1 + (E/E_{max})^s}, \quad (1)$$

where E_r , s , and R_{inf} are fitting parameters that have been fixed from [2] and [5] to 60eV, 1.813 and 0.2, respectively. E_{max} corresponds to the energy at which δ has its maximum value (δ_{max}). For stainless steel (RHIC), $E_{max}=300\text{eV}$ [6]. The contributions to $\delta(E)$ can be divided into the reflected electrons (terms proportional to R and R_{inf}) and the 'true' secondaries (terms proportional to SEY_{max}). R stands to the electron backscattering probability at low E , whereas R_{inf} refers for the same probability for high E electrons. The angular distribution of the secondary electrons is also taken into account and can be seen in [2]. Figure 1 illustrates the global behaviour of δ and the individual contribution of the reflected electrons and the true secondaries, respectively.

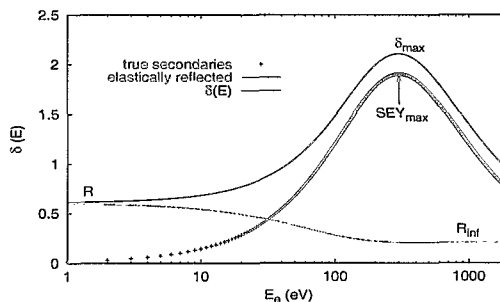


Figure 1: Separation between the processes influencing δ for $R=0.6$ and $SEY_{max}=1.9$.

EC is very sensitive to the SEY_{max} and R . By comparing *CSEC* results with experimental observations, we give a reliable range for these SEY_{max} and R referring to the RHIC beam pipe wall. On the other hand, the freedom to change these specific parameters in the input file using the *ECLOUD* code is reduced only to the value δ_{max} (Fig. 1). Note that δ_{max} is not the same as the SEY_{max} from *CSEC*. The way in which the reflected electrons are

* Work supported by US DOE under contract DE-AC02-98CH10886

† ubaldo@bnl.gov

evaluated in *ECLLOUD* is fixed. The parametrization used there has been updated following laboratory measurements. The latest version, which is the one used here, can be seen in [7].

3. SIMULATIONS COMPARED WITH EXPERIMENTAL DATA

Clear *EC* cases occurred during the RHIC FY2003 polarized proton (*pp*) run, where it was technically feasible to reach higher bunch intensities (I_{pb}) than during the *dAu* run. These cases occurred at the long straight section labeled 'bo2', where the vacuum chamber has cylindrical symmetry. The main machine characteristics, together with the beam parameters for fill #3460 can be seen at Table 1. Figure 2 shows a snapshot of the *EC* signal collected in the *ED* and the bunch intensity (I_{pb}) for fill #3460. I_{pb} ranges from $8 \cdot 10^{10}$ to $5.5 \cdot 10^{10}$ *ppb* during the bunch train. Note that the I_{pb} of the second group of less intense bunches (from bunch # 17 to 33) causes the *EC* signal to decrease. That may indicate a RHIC *EC* threshold of $I_{pb}=6 \cdot 10^{10}$ protons per bunch (*ppb*) for the long straight sections.

Table 1: Machine and beam specifications used for the RHIC simulations based on fill #3460.

I_{pb}	$8 \cdot 10^{10}$ <i>ppb</i>
full bunch length	15 ns
bunch spacing	106.6 ns
# bunches (N_b)	110
revolution period (T_{rev})	12.8 μs
rms beam radius	2.4 mm
relativistic γ	25.8
beam pipe radius	6 cm

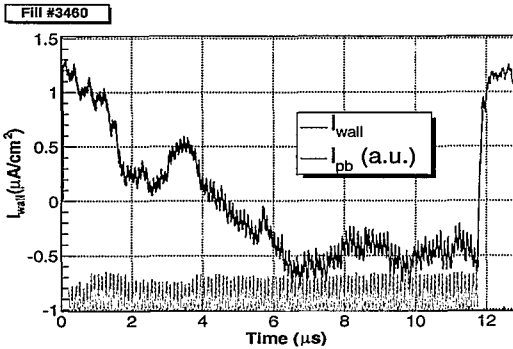


Figure 2: *EC* signal (black solid trace) and I_{pb} (red bars) for a RHIC revolution ($12.8 \mu s$ during fill 3460). The signal goes from positive to negative values due to the electronic design of the *ED*.

In general, the computer code simulations assume equal intensity along the bunch train. Fill #3460 can be reproduced with the recently developed *CSEC*, which allows I_{pb} to be changed for different bunches. We tried to fix the wall surface parameters contributing to *EC* by sweeping SEY_{max} and R and comparing I_{wall} behaviour with

the experimental data. Due to the few *EC* cases found until now, the electron dose received can be neglected. It turned out that $R < 0.5$ needs $SEY_{max} > 2.2$ to multipact (far from the literature values for baked stainless steel surfaces, see [5] and [6]), whereas $R = 0.7$ does not reproduce the observed decay time. Therefore, possible values for R are 0.6 ± 0.1 . Figure 3 shows the SEY_{max} sweep fixing $R = 0.6$. In order to determine the proper values of SEY_{max} and R , we could fit the growth and decay times from both simulations and experimental data and compare the results. However, the experimental data comes from an AC coupled signal with a low frequency cut off, $f_{low} = 300 \text{ kHz}$ [4]. Therefore, the signal needs to be treated before fitting when slow dynamics ($< 300 \text{ kHz}$) play a role, as they did for fill # 3460. This treatment is being developed, and the results of the first analysis indicate that $R = 0.6$ and $SEY_{max} = [1.8 - 2.0]$ match reasonably well with the estimated I_{wall} ($\approx 0.5 - 5 \frac{\mu A}{cm^2}$) and *EC* timing (saturation $\approx 6 \mu s$). This combination is also found in scientific papers ([5] and [6]). The combination $R = 0.5$ and $SEY_{max} \geq 2.1$ is a possibility for the unbaked stainless steel vacuum chambers at RHIC. Note that these values are given for $R_{inf} = 0.2$. Possible consequences of changes in this parameter are currently under study.

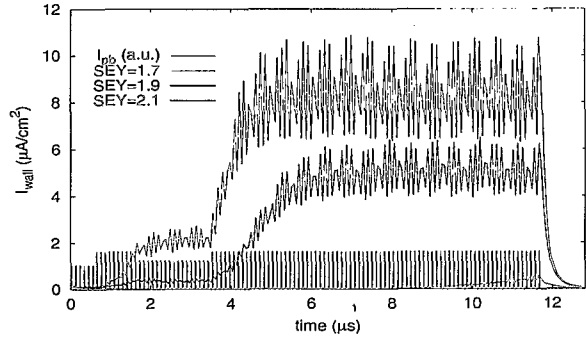


Figure 3: Sweep of possible values of SEY_{max} fixing $R = 0.6$. The maximum value of the line density for these cases ranges from 0.1 nC/m ($SEY_{max} = 1.7$) to 1 nC/m ($SEY_{max} = 2.1$).

Preliminary results using *ECLLOUD* with the latest parametrization for elastically reflected electrons using $\delta_{max} = 1.9$ produce a line density ρ at saturation on the order of 0.3 nC/m , which is in good agreement with *CSEC* results for $R = 0.6$ and $SEY_{max} = 1.8$.

4. RESULTS OF APPLYING A SOLENOID FIELD

Figure 2 shows that less intense bunches produce a strong decrease in the *ECE* signal. Therefore, it was thought that a fill pattern with some missing gaps could avoid the *EC* build-up. To check this possibility, RHIC was filled with the 110 bunch fill pattern, but using some gaps in the bunch train, i.e. the same beam and machine parameters stated in Table 1 except for $N_b = 41$ and $I_{pb} = 1.1$

10¹¹. In this case, 16 'filled' bunches were followed by a gap of 425ns (corresponding to 4 missing bunches). During the third bunch train, only 9 bunches were injected because of the high P rise. So, the total number of bunches is $N_b=16+16+9=41$. Fig. 4 shows this pattern as well as the EC signal. The EC signal was quite evident and stable and a solenoid field (B) was applied. As can be seen in Fig. 4 (top), a very weak B (5.4 Gauss) already decreases the EC at RHIC by a factor of ≈ 4 , and unfortunately sends the EC signal below the noise level. Observations with higher B did not show significant changes. Results from $CSEC$ simulations are shown on Fig.4 (bottom). According to Sec. 3, a good and reliable combination is $SEY_{max}=1.8$ and $R=0.6$. Simulation results for this case can be seen at Fig. 4 and confirm that $B=5.4$ Gauss is already a field strong enough to put the EC signal under the RHIC electron detector noise level. Further studies are currently carrying on to exactly determine the magnetic field suppressing EC at RHIC.

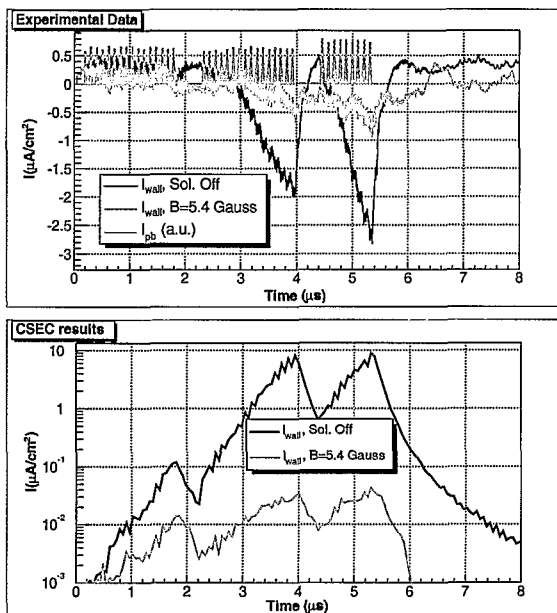


Figure 4: Experimental suppression of the EC using a solenoid (top). $B=5.4$ Gauss sends the EC signal to the noise level. The simulation results (bottom) show good agreement. Note a logarithmic scale is used for the simulation results to highlight the difference in the order of magnitude.

5. EVALUATION OF P

For I_{pb} and N_b fixed, the final I_{wall} is stabilized under certain conditions due to space charge effects. Observations show that the final P also reaches a certain equilibrium between the desorbed gas molecules in the wall and the gas pumped by the ion pumps. This P can be estimated directly proportional to I_{wall} ([1]) and depending on the electron desorption coefficient (η_e) of the beam pipe wall. This becomes a critical parameter for this calculation. Although η_e changes significantly depending on

the gas species, temperature, surface material and the impinging electron E ([9]), we plan to use RHIC to give a global (regardless the gas species) estimate for η_e based on the experimental observations for both I_{wall} and P . Unfortunately, the amount of data is still not enough to give a reliable value for η_e and further studies are currently being carried out.

6. CONCLUSIONS

Observations at RHIC and simulation development are currently being carried and therefore the analysis is not definitive. However, preliminary results from simulations show good agreement with the latest experimental data (I_{wall} on the order of 0.5-10 $\frac{\mu A}{cm^2}$). Both $CSEC$, $ECLOUD$ and experimental results show a $\rho \approx 0.5$ nC/m. We determined a value for $R=0.6 \pm 0.1$ for SEY_{max} (1.8-2.1) for baked stainless steel vacuum chambers used; and $SEY_{max} > 2.1$ for the unbaked case using $CSEC$ parametrization. However, variations on R_{inf} have not been considered, and these values may vary slightly. Weak solenoid fields (≈ 10 Gauss) are strong enough to suppress the cloud for $I_{pb} \approx 10^{11}$ ppb. We introduced also a preliminary plan to find a global value for η_e from the observations of P and I_{wall} .

ACKNOWLEDGEMENTS

The authors would like to thank D. Gassner, J. Gullotta, O. Gould, P. He, H.C. Hseuh, R. Lee, V. Ponnayyan, L. Smart, D. Trbojevic and S.Y. Zhang for their precious help in the data acquisition and understanding. The use of $ECLOUD$ would have not been possible without G. Rumolo.

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